NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM 26

SIMPLE MEANS FOR SAVING FUEL ON TRAFFIC FLIGHTS.

By

E. Kook.

Translated from
"Zeitschrift für Flugtechnik und Motorluftschiffahrt."
Vol. X, Nos. 17 and 18.

June, 1921.

with a small degree of throttling, but only to spare the engine. The maximum utilization of this simplest means of saving fuel is desirable, in spite of the consequent speed reduction, for many traffic airplanes, in the event of a head wind, for example, and on long trips to distant regions without rapid railroad communication.

Fig. 1 shows, with relation to the changed engine speed (r.p.m.) n, the flying speed V (with relation to the air) and the hourly fuel consumption B of a seaplane, which were measured by suitable methods, during careful horizontal flight at 500 meters altitude. $\frac{B}{V}$ gives the fuel consumption, b_R, of this airplane for one kilometer is still air (Fig. 2); b_r divided by the total weight or by the useful load (available carrying capacity) gives the fuel consumption respectively per total or per useful ton-kilometer.

According to the experiments, the value of b_R drops from the highest r.p.m. and flying speed rapidly at first (so that even slight throttling results in a comparatively large fuel saving with only a moderate sacrifice in speed) down to the r.p.m. and flying speed at which horizontal flight is only just possible and below which any further reduction would cause the airplane to fall. For the airplane tested, this was when n had dropped to about 1100 r.p.m. and V to 90 km. per hour. The throttling should, however, for the sake of safety and ease in steering, never be carried to this limit, but only to a certain higher speed. (In this instance n = 1200, V = 110 km.

per hour.) At the lower limit of this "practical" throttling (with about 20% lower flying speed), the fuel consumption per kilometer of flight is 17% less than with wide open throttle and maximum flying speed. Similar results were also obtained with other airplanes.

For economy of engine power alone, throttling is disadvantageous, since the specific consumption b_e per work unit increases with the decreasing revolution speed, on account of the accompanying decrease in load (in about the third power), as shown approximately by Fig. 2 (according to bench tests). The propeller efficiency suffers no substantial change from the throttling, since (according to Fig. 1) the revolution speed and flying speed are nearly proportional. The favorable result can hence be attributed only to the characteristics of the particular airplane and must be due to the fact that its head resistance diminishes with its speed. If the head resistance remained constant, the engine efficiency would diminish only in proportion to the speed, while the propeller thrust and the energy consumed per kilometer would remain the same, as likewise the fuel consumption. As a matter of fact, the fuel consumption (b_R) per km. diminishes with the diminishing speed (Fig. 2) and, at the same time, the head resistance W must diminish still more, on account of the diminishing efficiency of the transformation of the fuel into mechanical energy.

This result is in accordance with the fundamental principles of aerodynamics. With throttling and diminished speed, the air resistance would become less, but also the lift A, in proportion to the square of the latter, and horizontal flight would be no longer possible, unless, at the same time, the airplane were given a greater incidence, so that the lift would remain the same. Hereby W is further increased, without its attaining, however, like A, the same value as with unthrottled speed. The gliding angle $(\Phi = \frac{W}{A})$ also becomes more favorable.

According to experiments with models, every supporting surface and also every airplane has a most favorable incidence f (Fig. 3), for which the lift can be obtained with the least resistance. Thus $\frac{W}{A}$ and the angle Φ in Fig. 3 have a minimum value. Any other angle of incidence is less favorable.

Fig. 3 shows the lift curve in the known representation with the indefinite lift number c_a, with which

$$A = c_a \times \frac{v^2}{2} \times F \times \frac{\gamma}{g} \quad \text{(v is given here in m. per sec.)}$$

With diminishing c_a the speed must increase according to its square, so as to keep the lift constant (Fig. 4).

The most advantageous utilization of power and fuel would now be obtained, if this most favorable angle of incidence for the normal speed were made the basis for the maximum speed of traffic airplanes. This is impossible, however, for the reason that then, with lower speeds, the drag and propeller thrust would have to be increased for the same lift, according to Fig. 3; slow horizontal flight with throttled engine would be altogether impossible on account of the consequent decrease in the moment of torsion and propeller thrust; there would also be no reserve power for starting and climbing; and, furthermore, for readily understood reasons, the least loss of speed (with f) would be disastrous for landing. In building airplanes, a smaller, less favorable angle of incidence must therefore be adopted, in order that the most favorable angles of incidence (with diminished speed) may be reserved for landing and climbing. This relation is the principal source of fuel saving per kilometer, through throttling.

For climbing and landing, hence also for angles of incidence near f, only limited speeds are practicable, which can not be much higher for swift airplanes than for slow ones. The greater, therefore, the maximum speed of an airplane is, just so much less favorable angles of incidence must be employed in the lower part of the curve in Fig. 3. For this reason, a greater throttle range and consequent fuel saving can be attained with swift airplanes than with slow ones, though with a greater sacrifice of speed.

II. Carburetor Adjustment for Most Economical Fuel Consumption.

Most of the present airplane engines are adjusted more with reference to their greatest possible output, than for economy in fuel consumption. This was demonstrated by the experiments (Fig. 5) in which only the size of the fuel nozzles was changed, while the engine speed (r.p.m.) and throttle remained the same and the air intake nearly so. The total fuel consumption and the richness of the carburetor mixture increases with the size of the nozzles. The highest engine efficiency is obtained in the vicinity of nozzle a, with a certain minimum intake of fuel, and the engine was adjusted on this basis at the factory. A larger intake than this does not further increase the efficiency, since the intake of air is insufficient for the combustion of a larger amount of fuel. Consequently the excess of fuel is wasted, as shown by the rapidly rising specific consumption b per HP. By still further increasing the size of the nozzle and the fuel intake, the maximum efficiency is again reduced, for reasons not to be discussed here. A greater fuel intake than provided for by nozzle a never comes, therefore, into practical consideration.

On the contrary, smaller nozzles than a give a considerably higher efficiency. The total fuel consumption diminishes, the quantity of air is unchanged and the mixture is correspondingly poorer. Down to a certain limit, the engine efficiency is hereby increased, simply because the chemical combustion is more complete. The fuel consumption per HP therefore falls. The maximum output can, however, no longer be obtained, since, on account of the smaller total intake of fuel, less is now burnt, notwithstanding the sufficient supply of air. The output does not, however, drop so much on this account as the fuel intake, since, as already mentioned, the practical efficiency is now improved. The minimum specific fuel consumption is reached with nozzle d. The reduction in the size of the nozzles must, nevertheless, not be carried so far in practice, since most aviation engines then have a tendency to backfire, as sometimes also when the engine is cold, and in cold damp weather. This results from the intake of new gas into the cylinder while the residue of the previous charge is still burning, on account of the slow combustion rate of the poor mixture. A certain safety margin must be maintained with reference to this backfiring limit, so that smaller nozzles than c are not practicable.*

The war-airplane engines are now mostly adjusted for mixtures capable of giving the greatest output in energy and with fuel nozzles in the vicinity of a. A fuel saving, up to 8%, is attainable by readjusting them at c. The consequent output sacrifice is 9%, on account of the simultaneous decrease in the revolution speed of the propeller, which may however be reduced to only 6% by employing a new propeller with the former revolution speed. With supercompressed engines, it is possible, and usually allowable, to avoid this entirely, by a corresponding increase in gas intake.

This readjustment for a poorer fuel mixture results in a greater heating of the engine, especially of the exhaust valves, on account of the slower combustion. For most engines, however, a and c are allowable limits.

* The minimum fuel consumption occurs in a mixture containing 1.2 times, and the maximum output (corresponding to nozzle a) about 0.8 of the chemically required air quantity - according to Strombeck, Experiments with Automobile Engines (Untersuchungen an Automobilmotoren), "Oelmotor" 1913-14, and Neumann, Researches (Forschungsarbeiten) No. 79.

This readjustment may be made without removing the engine from the airplane. Consumption increases are not necessary in this connection. The object may be attained, by successively trying smaller nozzles (with a cold engine), down to the back-firing limit, and then adopting, for ultimate use, a nozzle somewhat larger than the one found to be the limit, for the sake of the above mentioned safety.

The behavior of over-compressed engines is fundamentally the same (Fig. 4). The adjustment must be made with the engine throttled for normal sea-level horsepower.

Aviation engines correctly regulated for gasoline are in all cases nearly correct for benzol, as demonstrated by many experiments.

According to the above, there is a goal for progress in the possibility of employing poorer mixtures without danger of back-firing. We can not now go into the methods for accomplishing this. Furthermore, according to comparative tests, most carburetors are capable of improvement with respect to the thorough mixing of air and fuel, which is essential for minimum fuel consumption.

III. Over-compression.

Most present-day engines, at least nearly all of those built since 1917, employ more or less over-compression, for lessening the falling off of engine power with increasing altitude. Only because in this connection, on account of the small heat evolution, the temperature of the walls of the combustion chamber (as well as that of the surrounding air) is lower, can the compression ratio be increased, without danger of pre-ignition. The higher compression ratio causes a diminution of fuel consumption and an increase of the average pressure, though the latter can be fully utilized only above a certain altitude. On the ground and at the low altitudes for air traffic, such an engine must be so strongly throttled, that the heating of the walls from the high compression remains correspondingly low.

With moderate over-compression ($\epsilon \approx 5.8$), it is usually sufficient to throttle down to the same sea-level horsepower obtained under normal compression $\epsilon \sim 5$ with throttle wide open. Stronger over-compression requires further throttling to a smaller sea-level horsepower. This is a disadvantage for air traffic at low altitudes, because the unit weight is thereby increased, even when the engine is over-dimensioned to correspond to the smaller maximum pressure resulting from the smaller middle pressure. In contrast with the increased horsepower and in spite of the throttling, there is still the advantage of smaller specific fuel consumption, even at sea-level. According to Fig. 4, there is a fuel saving of 6% with an over-compression of $\epsilon = 5.8$, as compared with the normal compression of $\epsilon = 5$. Consequently, even for air traffic engines, the retention of original application (through taller cylinders) of over-compression comes under consideration, but only to a certain limit not much higher than the above-mentioned value, which can not here be more definitely determined. Not all engines can stand over-compression, or at least not equally well. In types with insufficient cooling of the hottest parts of the walls of the combustion space, spark plugs, exhaust valves and cylinder bottoms, the permissible normal compression for complete charging at sea-level can only be small and, for this very reason it is, with this type of engines, often raised to the limit where spontaneous combustion occurs. In such a case, even a slight over-compression is only made possible by such strong throttling, that its practical application is out of the question.

The benzol fuels, which are of preponderant importance for air traffic, are less sensitive in this way, since they can stand a higher compression than gasoline, on account of their higher kindling temperature and slower combustion rate.

According to war experience, no disadvantage arose from moderate over-compression and there islikewise none to be feared in air traffic. For avoiding excessive stresses, care must be taken to render even the temporary delivery of "altitude gas" above sea-level horsepower impossible.

Engines with strong over-compression are somewhat sensitive only to a sudden stopping when heated from running under full load. With the last revolutions there then occur, in spite of the switching off of the electric ignition, violent self-ignitions which cause back strokes of the engine with strong stresses. This is however prevented when the stop is made gradually, as it should be for any aviation engine, after it hasrun empty for several minutes and become partially cooled.

IV. Choice of a Suitable Propeller for Horizontal Flight.

Many war airplanes have propellers with more or less one-sided climbing ability. These work at a disadvantage in horizontal flight and thereby increase the fuel consumption.

In climbing, the flying speed is much slower than in horizontal flight and the revolution speed of the propeller is likewise less. For obtaining the greatest climbing efficiency, propellers were employed which, even with the low climbing speed, had almost the maximum allowable revolution speed and climbed with a good degree of efficiency. In horizontal flight, these propellers worked with an unfavorably high revolution speed, both for the engine drive and for propeller efficiency. A greater flying speed and a more efficient utilization of the fuel is obtained with propellers which, in horizontal flight, have only the maximum allowable revolution speed (about 1400 r.p.m. for fixed engines) with good efficiency. Only such propellers are suitable for air traffic.

Summary.

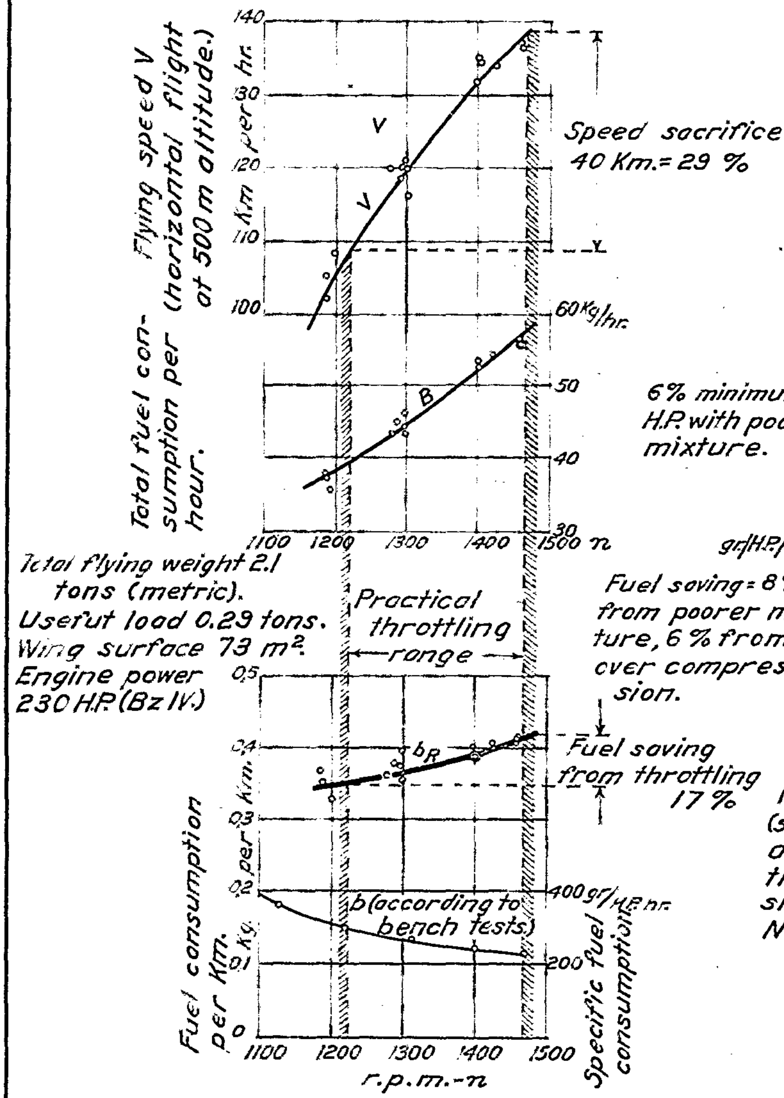
By flying with throttled engine and diminished speed, without reference to the wind, the fuel consumption is lessened and all the more with stronger throttling. In experiments on airplanes with a low maximum speed, throttling within practical flying limits resulted in a fuel saving of 17%.

Over-compression should be employed on air traffic engines, for the sake of the fuel economy thereby attainable.

The carburetors of most engines can be adjusted so as to save fuel, with only a slight sacrifice in power.

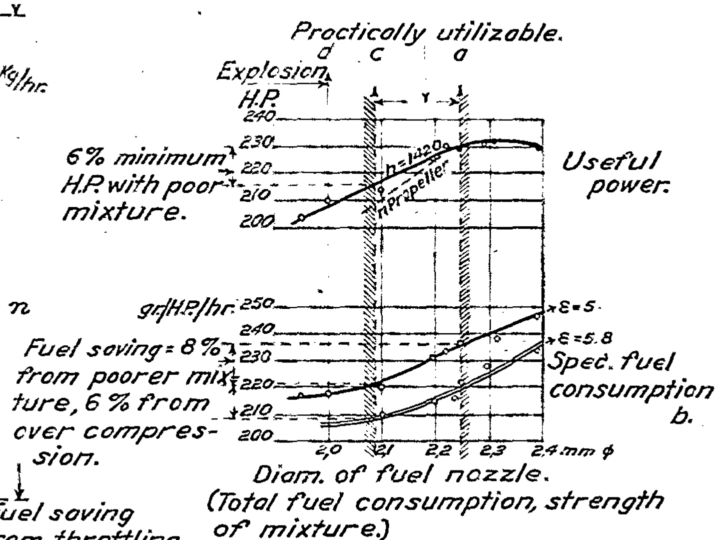
Speed propellers are the most economical for air traffic airplanes.

Translated by National Advisory Committee for Aeronautics.



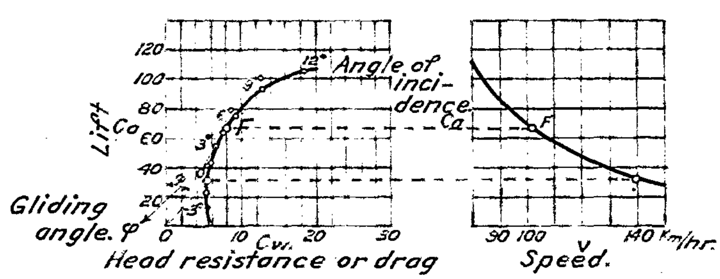
Speed, total fuel consumption and fuel consumption per km. flight with relation to the r.p.m. in horizontal flight at 500 m. altitude.

Figs. 1 and 2.



Influence of size of fuel nozzle (strength of mixture) on performance (H.P.) and spec. fuel consumption. Influence of over-compression on latter in Bz. IV- engine No. 34,095.

Fig. 5.



Figs. 3. and 4.

(Footnote to Fig. 4.)

Lift curve of a biplane model according to Munk and Molthan. Bulletin No. 20 of the Göttingen Model-testing Institute for Aerodynamics (Mitteilung 20 der Göttingen Modellversuchsanstalt für Aerodynamik).